

1           1. A method of characterizing a color imaging  
2 system, the method comprising:  
3           obtaining first data indicative of output of the  
4 color imaging system;  
5           processing the first data, to yield second data,  
6 according to a color appearance model that varies in  
7 accordance with neutrality of colors indicated by the first  
8 data.

1           2. The method of claim 1 wherein the color  
2 appearance model varies according to a white reference  
3 vector that is a weighted combination of a local white point  
4 of the color imaging system and a common white point, the  
5 white reference vector being weighted more to the local  
6 white point the more a color indicated by the first data is  
7 neutral and being weighted more to the common white point  
8 the more the indicated color is saturated.

1           3. The method of claim 2 wherein the color imaging  
2 system is an emissive system and processing the first data  
3 includes using a media white point as the local white point  
4 to implement absolute colorimetry.

1           4. The method of claim 1 wherein the color  
2 appearance model varies as a function of intensity of the  
3 color indicated by the first data.

1           5. The method of claim 4 wherein the color  
2 appearance model includes a luminance descriptor, and a pair  
3 of color descriptors that quantify relative amounts of red,  
4 green, yellow, and blue in a color indicated by the second  
5 data;

6           wherein the luminance descriptor varies as a  
7   function of Y, Y being one of tristimulus values X, Y, and Z  
8   of the color indicated by the first data; and

9           wherein the pair of color descriptors vary as  
10   functions of the neutrality of the color indicated by the  
11   first data.

1           6. The method of claim 5 wherein the luminance  
2   descriptor varies as a function of a Y-reference that is a  
3   weighted combination of a local white point Y-value and a  
4   common white point Y-value, the Y-reference being weighted  
5   more toward the local white point Y-value the closer the Y-  
6   value of the color indicated by the first data is to the  
7   local white point Y-value and being weighted more toward the  
8   common white point Y-value the more the Y-value of the color  
9   indicated by the first data and the local white point Y-  
10   value differ.

1           7. The method of claim 6 wherein the second data  
2   include values for L\*, a\*, and b\*; and

3           wherein

4            $L^* = 116 \times f(Y/Y_n'') - 16$

5            $Y_n'' = Y_{LW}(1 - \text{sat}(Y, Y_{LW})) + Y_{CW} * \text{sat}(Y, Y_{LW})$

6            $\text{sat}(Y, Y_{LW}) = 1.0 - (Y/Y_{LW})$

7            $a^* = 500(f(X/X_n') - f(Y/Y_n'))$

8            $b^* = 200(f(Y/Y_n') - f(Z/Z_n'))$

9            $f(\omega) = (\omega)^{1/3} \quad \omega > 0.008856$

10           $f(\omega) = 7.787(\omega) + 16/116 \quad \omega \leq 0.008856$

11           $X_n' = X_{LW}(1 - \text{sat}(C, C_{LW})) + X_{CW} * \text{sat}(C, C_{LW})$

12           $Y_n' = Y_{LW}(1 - \text{sat}(C, C_{LW})) + Y_{CW} * \text{sat}(C, C_{LW})$

13           $Z_n' = Z_{LW}(1 - \text{sat}(C, C_{LW})) + Z_{CW} * \text{sat}(C, C_{LW})$

14           $C = (X, Y, Z)$

15           $C_{LW} = (X_{LW}, Y_{LW}, Z_{LW})$

```
16      sat(C, CLW) = (devX' Y' Z' / maxDev)γ  
17      maxDev=sqrt(6.0/9.0) * max(X', Y', Z')  
18      devX' Y' Z' = sqrt((X'-avgX' Y' Z')2+(Y'-avgX' Y' Z')2  
19          +(Z'-avgX' Y' Z')2)  
20      avgX' Y' Z' = (X' + Y' + Z')/3.0  
21      X'=X/XLW  
22      Y'=Y/YLW  
23      Z'=Z/ZLW
```

24 where  $C_{LW}$  is a local white vector representing a local white  
25 point of the system,  $C_{CW}=(X_{CW}, Y_{CW}, Z_{CW})$  is a common white vector  
26 for a common white point of the system, and  $\gamma$  is a variable  
27 for scaling the local white vector  $C_{LW}$  relative to the  
28 common white vector  $C_{CW}$ .

1       8. The method of claim 5 wherein the second data  
2 include values for L\*, a\*, and b\*;

3           wherein L\* is closer to a relative colorimetric  
4 value of L\* than an absolute colorimetric value of L\* the  
5 closer the value of Y is to a local white point value Y<sub>LW</sub>;  
6 and

7           wherein a\* and b\* are closer to relative colorimetric  
8 values of a\* and b\*, respectively, than to absolute  
9 colorimetric values of a\* and b\*, respectively, the closer  
10 the indicated color is to neutral.

1       9. The method of claim 8 wherein

```
2       L*=(1.0-sat_L*) * L*rel + sat_L* * L*abs;  
3       a*=(1.0-sat_a*b*) * a*rel + sat_a*b* * a*abs;  
4       b*=(1.0-sat_a*b*) * b*rel + sat_a*b* * b*abs;  
5       sat_L*=1.0-(Y/YLW);  
6       sat_a*b*=(sqrt(a*2 + b*2))/L*; and  
7       wherein L*rel, a*rel, and b*rel are values of L*, a*,  
8 and b*, respectively, using relative colorimetry, and L*abs,
```

9       $a^*_{abs}$ , and  $b^*_{abs}$  are values of  $L^*$ ,  $a^*$ , and  $b^*$ , respectively,  
10     using absolute colorimetry.

1            10. A computer program product residing on a  
2     computer readable medium, for characterizing a color imaging  
3     system, comprising instructions for causing a computer to:  
4                obtain first data indicative of output of the color  
5     imaging system;  
6                process the first data, to yield second data,  
7     according to a color appearance model that varies in  
8     accordance with neutrality of a color indicated by the first  
9     data.

1            11. The computer program product of claim 10  
2     wherein the color appearance model varies according to a  
3     white reference vector that is a weighted combination of a  
4     local white point of the color imaging system and a common  
5     white point, the white reference vector being weighted more  
6     to the local white point the more a color indicated by the  
7     first data is neutral and being weighted more to the common  
8     white point the more the indicated color is saturated.

1            12. The computer program product of claim 11  
2     wherein the color imaging system is an emissive system and  
3     the instructions for causing the computer to process the  
4     first data cause the computer to use a media white point as  
5     the local white point to implement absolute colorimetry.

1            13. The computer program product of claim 10  
2     wherein the color appearance model varies as a function of  
3     intensity of the color indicated by the first data.

1           14. The computer program product of claim 13  
2   wherein the color appearance model includes a luminance  
3   descriptor, and a pair of color descriptors that quantify  
4   relative amounts of red, green, yellow, and blue in a color  
5   indicated by the second data;

6           wherein the luminance descriptor varies as a  
7   function of Y, Y being one of tristimulus values X, Y, and Z  
8   of the color indicated by the first data; and

9           wherein the pair of color descriptors vary as  
10   functions of the neutrality of the color indicated by the  
11   first data.

1           15. The computer program product of claim 14  
2   wherein the luminance descriptor varies as a function of a  
3   Y-reference that is a weighted combination of a local white  
4   point Y-value and a common white point Y-value, the Y-  
5   reference being weighted more toward the local white point  
6   Y-value the closer the Y-value of the color indicated by the  
7   first data is to the local white point Y-value and being  
8   weighted more toward the common white point Y-value the more  
9   the Y-value of the color indicated by the first data and the  
10   local white point Y-value differ.

1           16. The computer program product of claim 15  
2   wherein the second data include values for L\*, a\*, and b\*;  
3   and

4           wherein

5            $L^* = 116 \times f(Y/Y_n'') - 16$

6            $Y_n'' = Y_{LW} (1 - sat(Y, Y_{LW})) + Y_{CW} * sat(Y, Y_{LW})$

7            $sat(Y, Y_{LW}) = 1.0 - (Y/Y_{LW})$

8            $a^* = 500 (f(X/X_n') - f(Y/Y_n'))$

9            $b^* = 200 (f(Y/Y_n') - f(Z/Z_n'))$

10            $f(\omega) = (\omega)^{1/3} \quad \omega > 0.008856$

```

11      f(ω) = 7.787(ω) + 16/116      ω ≤ 0.008856
12      Xn' = XLW(1 - sat(C, CLW)) + XCW * sat(C, CLW))
13      Yn' = YLW(1 - sat(C, CLW)) + YCW * sat(C, CLW))
14      Zn' = ZLW(1 - sat(C, CLW)) + ZCW * sat(C, CLW))
15      C = (X, Y, Z)
16      CLW = (XLW, YLW, ZLW)
17      sat(C, CLW) = (devX' Y' Z' / maxDev)γ
18      maxDev = sqrt(6.0/9.0) * max(X', Y', Z')
19      devX' Y' Z' = sqrt((X' - avgX' Y' Z')2 + (Y' - avgX' Y' Z')2
20          + (Z' - avgX' Y' Z')2)
21      avgX' Y' Z' = (X' + Y' + Z') / 3.0
22      X' = X / XLW
23      Y' = Y / YLW
24      Z' = Z / ZLW

```

25 where C<sub>LW</sub> is a local white vector representing a local white  
 26 point of the system, C<sub>CW</sub> = (X<sub>CW</sub>, Y<sub>CW</sub>, Z<sub>CW</sub>) is a common white vector  
 27 for a common white point of the system, and γ is a variable  
 28 for scaling the local white vector C<sub>LW</sub> relative to the  
 29 common white vector C<sub>CW</sub>.

1           17. A method of producing a color on a device, the  
 2 method comprising:  
 3           obtaining first data associated with a first device  
 4 and indicative of a first color;  
 5           determining second data related to stimulus data of  
 6 the first device by a color appearance model that converts  
 7 input data to output data using a white reference vector  
 8 that varies in association with a neutrality of a color  
 9 indicated by the input data;  
 10          actuating a second device according to the second  
 11 data to produce a second color to approximate the first  
 12 color.

1           18. The method of claim 17 wherein the white  
2 reference vector approaches a white point associated with  
3 first device as the color indicated by the input data  
4 approaches a neutral color.

1           19. The method of claim 18 wherein the color  
2 appearance model includes a luminance descriptor, and a pair  
3 of color descriptors that quantify relative amounts of red,  
4 green, yellow, and blue in a color indicated by the output  
5 data;

6           wherein the luminance descriptor varies as a  
7 function of Y, Y being one of tristimulus values X, Y, and Z  
8 of the color indicated by the first data; and

9           wherein the pair of color descriptors vary as  
10 functions of the neutrality of the color indicated by the  
11 first data.

1           20. The method of claim 17 wherein the first data  
2 are first device stimulus data of the first device and the  
3 second data are second device stimulus data of the second  
4 device, and determining the second data comprises mapping  
5 third data to fourth data, the third data being converted  
6 from the first data using the color appearance model and the  
7 fourth data being converted from the second data using the  
8 color appearance model.

1           21. A computer program product residing on a  
2 computer readable medium, for producing a color on a device,  
3 comprising instructions for causing a computer to:

4           obtain first data associated with a first device and  
5 indicative of a first color;

6           determine second data related to stimulus data of  
7 the first device by a color appearance model that converts

8       input data to output data using a white reference vector  
9       that varies in association with a neutrality of a color  
10      indicated by the input data;  
11           actuate a second device according to the second data  
12      to produce a second color to approximate the first color.

1           22. The computer program product of claim 21  
2       wherein the white reference vector approaches a white point,  
3       associated with each device whose data are used as the input  
4       data, as the color indicated by the input data approaches  
5       white or a neutral color.

1           23. The computer program product of claim 21  
2       wherein the first data are first device stimulus data of the  
3       first device and the second data are second device stimulus  
4       data of the second device, and the instructions that cause  
5       the computer to determine the second data cause the computer  
6       to map third data to fourth data, the third data being  
7       converted from the first data using the color appearance  
8       model and the fourth data being converted from the second  
9       data using the color appearance model.

1           24. A method of producing a color with an emissive  
2       device using absolute colorimetry, the method comprising:  
3           obtaining first data indicative of a first color;  
4           determining second data related to the first data by  
5       a color appearance model that uses a white point of the  
6       emissive device as a white reference vector;  
7           actuating the emissive device according to the  
8       second data to implement absolute colorimetry to produce a  
9       second color to approximate the first color.

1           25. The method of claim 24 wherein the white  
2 reference vector varies in association with neutrality of  
3 colors to be produced on the emissive device.

1           26. The method of claim 25 wherein the white  
2 reference vector varies from the white point of the emissive  
3 device when the second color is near white to a common white  
4 reference, different from the white point of the emissive  
5 device, when the second color departs from a near-white,  
6 neutral color.

1           27. A computer program product residing on a  
2 computer readable medium, for producing a color with an  
3 emissive device using absolute colorimetry, comprising  
4 instructions for causing a computer to:  
5           obtain first data indicative of a first color;  
6           determine second data related to the first data by a  
7 color appearance model that uses a white point of the  
8 emissive device as a white reference vector;  
9           actuate the emissive device according to the second  
10 data to implement absolute colorimetry to produce a second  
11 color to approximate the first color.

1           28. A method of characterizing an emissive device  
2 for absolute colorimetry, the method comprising:  
3           obtaining first data indicative of output of the  
4 emissive device;  
5           converting the first data to second data using a  
6 color appearance model that uses a white point of the  
7 emissive device as a reference white vector;  
8           providing the second data for use in absolute  
9 colorimetric color reproduction.

1           29. The method of claim 28 wherein converting the  
2 first data to second data further includes using, as the  
3 white reference vector, a composite white reference vector  
4 that is a weighted combination of the white point of the  
5 emissive device and a predetermined white point, the  
6 composite white reference vector being closer to the white  
7 point of the emissive device the closer a color indicated by  
8 the first data is to being neutral.

1           30. A computer program product residing on a  
2 computer readable medium, for characterizing an emissive  
3 device for absolute colorimetry, comprising instructions for  
4 causing a computer to:

5           obtain first data indicative of output of the  
6 emissive device;

7           convert the first data to second data using a color  
8 space that uses a white point of the emissive device as a  
9 reference white vector;

10          provide the second data for use in absolute  
11 colorimetric color reproduction.

1           31. A method of characterizing colors for  
2 reproduction between a first device and a second device, the  
3 method comprising:

4           normalizing first tristimulus values indicative of a  
5 color of the first device using local black point values;

6           transforming the normalized first tristimulus values  
7 to obtain color values indicative of modified cone responses  
8 of the human eye;

9           chromatically adapting the color values from a local  
10 condition to a reference condition; and

11          transforming the adapted color values to obtain  
12 second tristimulus values.

1           32. The method of claim 31 wherein a neutral axis  
2 of the local condition is mapped to a neutral axis of the  
3 reference condition.

1           33. The method of claim 31 wherein normalizing the  
2 first tristimulus values includes dividing by a difference  
3 between a local luminance value and a local black point  
4 luminance value.

1           34. The method of claim 33 wherein transforming the  
2 adapted color values includes multiplying the adapted color  
3 values by a reference white point luminance value divided by  
4 a difference between a local white point luminance value and  
5 the local black point luminance value.

1           35. The method of claim 31 wherein transforming the  
2 normalized first tristimulus values is performed using a  
3 Bradford transformation.

1           36. The method of claim 35 wherein normalizing the  
2 first tristimulus values and transforming the normalized  
3 first tristimulus values are performed according to

4        $[R_1] = [(X_1 - X_{1k}) / (Y_1 - Y_{1k})]$

5        $|G_1| = M_b |(Y_1 - Y_{1k}) / (Y_1 - Y_{1k})|$

6        $[B_1] = [Z_1 - Z_{1k}] / (Y_1 - Y_{1k})]$

7 where  $[X_{1k}, Y_{1k}, Z_{1k}]$  is the local black point,  $X_1$ ,  $Y_1$ , and  $Z_1$   
8 are the first tristimulus values,

9        $[0.8951 \ 0.2664 \ -0.1614]$

10       $M_b = [-0.7502 \ 1.7135 \ 0.0367]$

11       $[0.0389 \ -0.0685 \ 1.0296]$ , and

12       $R_1$ ,  $G_1$ , and  $B_1$  are the color values indicative of modified  
13 cone responses of the human eye.

1           37. The method of claim 36 wherein chromatically  
2 adapting the color values is performed according to

3            $R_{ref} = (R_{rw}/R_{lw}) \times R_l$

4            $G_{ref} = (G_{rw}/G_{lw}) \times G_l$

5            $B_{ref} = \text{Sign}[B_l] \times (B_{rw}/B_{lw})^{\beta} \times |B_l|^{\beta}$

6            $\beta = (B_{lw}/B_{rw})^{0.0834}$

7 where  $R_{rw}$ ,  $G_{rw}$ , and  $B_{rw}$  are RGB values of a reference white  
8 point,  $R_{lw}$ ,  $G_{lw}$ , and  $B_{lw}$  are RGB values of a local white  
9 point.

1           38. The method of claim 37 wherein transforming the  
2 adapted color values to second tristimulus values is  
3 performed according to

4            $[X_{ref}] = [R_{ref} \times Y_l \times Y_{rw}/(Y_{lw} - Y_{lk})]$

5            $|Y_{ref}| = M_b^{-1} [G_{ref} \times Y_l \times Y_{rw}/(Y_{lw} - Y_{lk})]$

6            $[Z_{ref}] = [B_{ref} \times Y_l \times Y_{rw}/(Y_{lw} - Y_{lk})]$ .

1           39. The method of claim 31 wherein transforming the  
2 normalized first tristimulus values is performed using a von  
3 Kries transformation.

1           40. The method of claim 39 wherein

2            $[X_{ref}] = [L_{rw} \ 0 \ 0] [1/(L_{lw}-L_{lk}) \ 0 \ 0] [X_l]$

3            $|Y_{ref}| = M_v^{-1} [0 \ M_{rw} \ 0] [0 \ 1/(M_{lw}-M_{lk}) \ 0] [Y_l]$

4            $[Z_{ref}] = [0 \ 0 \ S_{rw}] [0 \ 0 \ 1/(S_{lw}-S_{lk})] [Z_l]$

5 where

6            $[0.38791 \ 0.68898 \ -0.07868]$

7            $M_v = [-0.22981 \ 1.18340 \ 0.04641]$

8            $[0 \ 0 \ 1.0]$

9 and where [L<sub>rw</sub>, M<sub>rw</sub>, S<sub>rw</sub>] are LMS (long, medium, and short  
10 wavelength band) values of the reference white, [L<sub>lw</sub>, M<sub>lw</sub>,  
11 S<sub>lw</sub>] are LMS values for local white, [L<sub>lk</sub>, M<sub>lk</sub>, S<sub>lk</sub>] are LMS  
12 values for local black, X<sub>l</sub>, Y<sub>l</sub>, and Z<sub>l</sub> are the first  
13 tristimulus values, and X<sub>ref</sub>, Y<sub>ref</sub>, and Z<sub>ref</sub> are the second  
14 tristimulus values.

1           41. The method of claim 31 wherein the first device  
2 is a print device and the second device is a print device,  
3 tristimulus values of a common illuminant are used as  
4 reference tristimulus white values for both print devices,  
5 media white tristimulus values of each print device are used  
6 as local tristimulus white values for both print devices,  
7 and Bradford-type adaptations are used for both print  
8 devices to implement media-relative colorimetry.

1           42. The method of claim 31 wherein the first device  
2 is a print device and the second device is a display device,  
3 tristimulus values of a reference illuminant are used as  
4 reference tristimulus white values, media white tristimulus  
5 values of the print device are used as local tristimulus  
6 white values for the print device, monitor white tristimulus  
7 values of the display device are used as local tristimulus  
8 values for the display device, and Bradford-type adaptations  
9 are used for both the first and second devices to implement  
10 media-relative colorimetry.

1           43. The method of claim 31 wherein the first device  
2 is a print device and the second device is a display device,  
3 tristimulus values of a reference illuminant are used as  
4 reference tristimulus white values, media white tristimulus  
5 values of the print device are used as local tristimulus  
6 white values, monitor white tristimulus values of the

7 display device are used as local tristimulus values for the  
8 display device, Bradford-type adaptation is used for the  
9 display device, and absolute CIE-Lab is used for the print  
10 device to implement absolute colorimetry.